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NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

THESIS

USE CASE ANALYSIS: THE AMBULATORY EEG IN NAVY MEDICINE FOR TRAUMATIC BRAIN INJURIES

by

Tahnyah D. Burner

December 2016

Thesis Advisor: Robert J. Eger
Co-Advisor: Bryan J. Hudgens

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USE CASE ANALYSIS: THE AMBULATORY EEG IN NAVY MEDICINE FOR TRAUMATIC BRAIN INJURIES

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MASTER OF BUSINESS ADMINISTRATION

from the

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ABSTRACT

Implementing the ambulatory electroencephalograph (EEG) system can expedite potentially emergent results, reduce patients' time spent in the hospital, eliminate the need for specialized technicians to administer the electrodes, reduce the bulky EEG equipment that takes up space and limited resources, and eliminate the need for a specialized physician to be present at the site to read the EEG report. This use case analysis details the processes involved with the ambulatory EEG concerning traumatic brain injuries and advises on the best uses of the device for naval medicine.

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LIST OF ACRONYMS AND ABBREVIATIONS

AD	Alzheimer's Disease
ALS	Amyotrophic lateral sclerosis
AMS	Altered Mental Status
EEG	Electroencephalograph
CAT	Computerized Axial Tomography
CHCS	Composite Health Care System
CT	Computed Tomography
DOD	Department of Defense
DTI	Diffusion Tensor Imaging
ED	Emergency Department
FDA	Food and Drug Administration
fMRI	Functional Magnetic Resonance Imaging
MACE	Military Acute Concussion Evaluation
MRI	Magnetic Resonance Imaging
mTBI	Mild Traumatic Brain Injury
NCS	Non-Convulsive Seizures
PD	Parkinson's Disease
QEEG	Quantitative EEG
SPECT	Single-Photon Emission Computerized Tomography
TBI	Traumatic Brain Injury

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EXECUTIVE SUMMARY

Treating service members who have suffered traumatic brain injuries (TBI) has become a priority within the Department of Defense and Veteran's Health Administration. In order to understand and treat those who have suffered TBIs, emphasis has been placed on research and proper treatment for service members and veterans that have suffered TBIs. As there are a few diagnostic imaging resources that can scan and detect muscular, skeletal, and blood abnormalities, the electroencephalograph (EEG) is used to detect the extent of a brain injury that a patient has suffered.

The standard EEG is expensive, bulky, and extremely sensitive to outside electrical interferences, which makes it difficult to capture an accurate recording when used in the emergency department. The EEG is commonly housed in an EEG lab where there are no electrical interferences. In addition, a specialized technician is required to attach the electrodes and operate the EEG machine. Alternatively, the ambulatory EEG is wireless, portable, comparable in the accuracy of its recordings to the standard EEG, and does not require a specialized technician. The ambulatory EEG is also less expensive and can be used anywhere without the risk of electrical interferences that could cause inaccurate results.

Due to the ambulatory EEG's portability and comparable accuracy, it can be used in an emergency room setting, clinical setting, and field/combat zones. Since the device does not require a specialized technician, it can be operated by a medical professional that has been trained on the proper care and use. After the ambulatory EEG has completed its recording, the information can be sent to a computer or mobile device via Bluetooth, which can then be sent as an email to any physician or neurologist positioned around the world. This would improve patient care by allowing physicians that may not be in the same location as the patient to diagnose and recommend a plan of care that can expeditiously aid a service member in need.

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I. INTRODUCTION

This study examines the diagnosis of traumatic brain injuries (TBI). Early detection and diagnosis is imperative in caring for injured patients to deter or prevent possible long-term damage associated with head trauma. The primary diagnostic approach that assists in determining the level or extent of an injury by measuring brain waves is the electroencephalograph (EEG).

The purpose of this thesis is to explain the following: the importance of the EEG machine, the introduction of a new portable and comparably accurate device (ambulatory EEG), the relevance that the ambulatory EEG has for naval medicine, the best uses for the ambulatory EEG within military medicine, and recommendations for the use of EEG on a ship or submarine and with military family members.

The military has expressed the importance of researching and treating service members affected by head trauma and the future physical, mental, and emotional implications the trauma can have on that person. The Assistant Secretary of Defense issued a memorandum to the Assistant Secretaries of the Army, Navy, and Air Force that identifies traumatic brain injuries as a very serious problem and directs the development of appropriate programs to aid those that have suffered from TBIs.

TBI, whether mild, moderate, or severe, is a significant health concern for both the Department of Defense (DOD) and the Department of Veterans Affairs. Identification, treatment, and long-term prognosis of TBI is an emerging science. Many affected with mild TBI will fully recover, and some will have persistent symptoms; the full extent of clinical effects is unknown. This work builds on the outstanding work completed in this area by the military departments into a comprehensive DOD program to identify, treat, document, and follow up those who have suffered a TBI while either deployed or in garrison (Winkenwerder, 2007).

The most common head injuries presented in service members are mild traumatic brain injuries (mTBIs), which can include concussions and sub-concussions (McKee & Robinson, 2014). According to medical professionals, a TBI is an interruption in brain

function caused by a strike to the head. The disruption may knock out an individual or cause disorientation or alteration of consciousness (Defense and Veterans Brain Injury Center, 2016). Some causes of TBIs that have been examined in deployed and non-deployed military personnel are blasts, bullets, fragments, falls, motor vehicle crashes and rollovers, sports, and assaults (McKee & Robinson, 2014). A description of the physical, cognitive, and emotional signs and symptoms commonly associated with TBIs may be found in Figure 1.

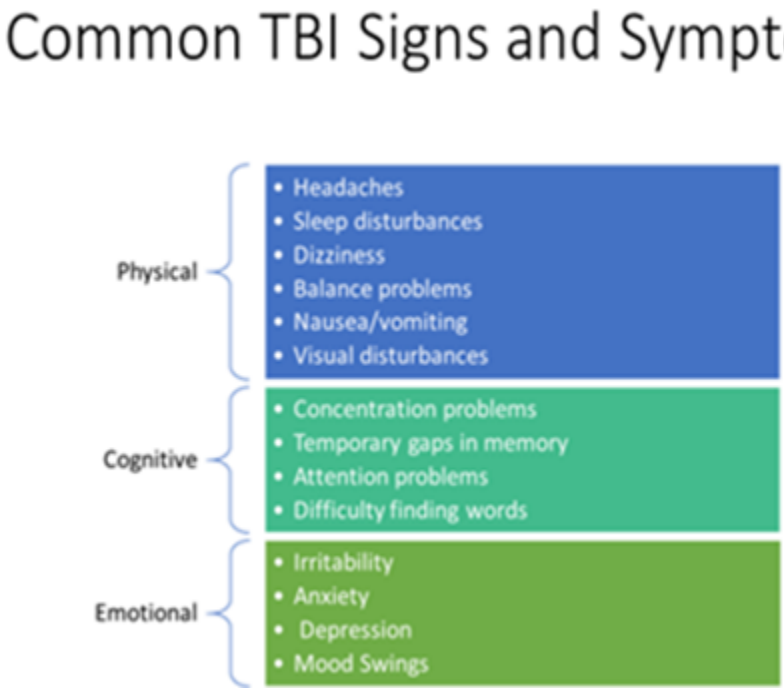

Figure 1. Traumatic Brain Injury Signs and Symptoms.
Source: Defense and Veterans Brain Injury Center (2016b).

Studies have shown that moderate to severe TBI is associated with long-term chronic effects and the eventual development of Alzheimer's disease (AD), Parkinson's disease (PD), and amyotrophic lateral sclerosis (ALS) (McKee & Robinson, 2014). McKee and Robinson described evidence of long-term effects caused by brain injury and its impacts to AD, PD, and other diseases:

> Increasing evidence suggests that a single traumatic brain injury can produce long-term gray and white matter atrophy, precipitate or accelerate

> age-related neurodegeneration, and increase the risk of developing Alzheimer's disease, Parkinson's disease, and motor neuron disease. Less severe impact injuries that do not produce overt neurological symptoms but are associated with subtle neuro-psychiatric deficits or changes in functional magnetic resonance imaging (fMRI) are referred to as "sub-concussion." (2014 p. 1)

McKee and Robinson (2014) observed that veterans who fought in World War II and had experienced a TBI were at least twice as likely to develop AD later in life than those who had not suffered a TBI. Military clinical guidelines were established to assist medical professionals whose patients screened positive for mTBIs, and if administered early, these guidelines can aid in the early intervention of affected persons and improve patient outcomes (U.S. Department of Veterans Affairs, 2016). In conjunction with the clinical guidelines, military physicians use the Military Acute Concussion Evaluation (MACE) as a screening tool to ascertain whether a patient has suffered a TBI. The MACE assessment also helps physicians determine whether the patient is stable or requires further care (Defense and Veterans Brain Injury Center, 2016a).

A. BACKGROUND

One of the primary diagnostic tools used to determine the extent of a brain injury is an EEG. An EEG measures brain waves and reports whether someone has suffered a brain injury or a disorder such as seizure disorders (such as epilepsy), concussions, head injuries, encephalitis (an inflammation of the brain), brain tumors, encephalopathy (a disease that causes brain dysfunction), memory problems, sleep disorders, strokes, and dementia (Zehtabchi, Baki, Omurtag, Sinert, Chari, Malhotra, Weedon, Fenton, and Grant, 2013). An EEG also measures the brain activity of coma patients or during brain surgery, in which the electrodes are attached to the brain (Zehtabchi et al., 2013).

The EEG is an important tool, because "while imaging studies such as computed tomography (CT) or magnetic imaging provide anatomical data, electroencephalography is the only readily available test which provides information about the functional status of the brain" (Zehtabchi et al., 2013).

Omurtag et al. (2012) noted that when EDs use EEGs, patient care is improved by decreasing unnecessary tests, admissions, procedures, and costs that would otherwise be involved with those who may be presented with altered mental status (AMS).

While the EEG is one of the most widely used tests for determining the extent of electro-cerebral activity, it continues to be an underused test in the ED (Bautista, Godwin, & Caro, 2007). Bautista et al. (2007) continued by providing some reasons why the EEG is not utilized more often: ER physicians may not understand the use of the EEG for patients that present with AMS and the setup time needed to perform an EEG. Figures 2, 3, and 4 display images of a standard EEG cap, EEG machine, and an EEG recording.

Figure 2. Standard EEG Cap. Source: Binaural Brains (n.d.).

Figure 3. EEG Machine. Source: Refine Medical Technology (n.d.).

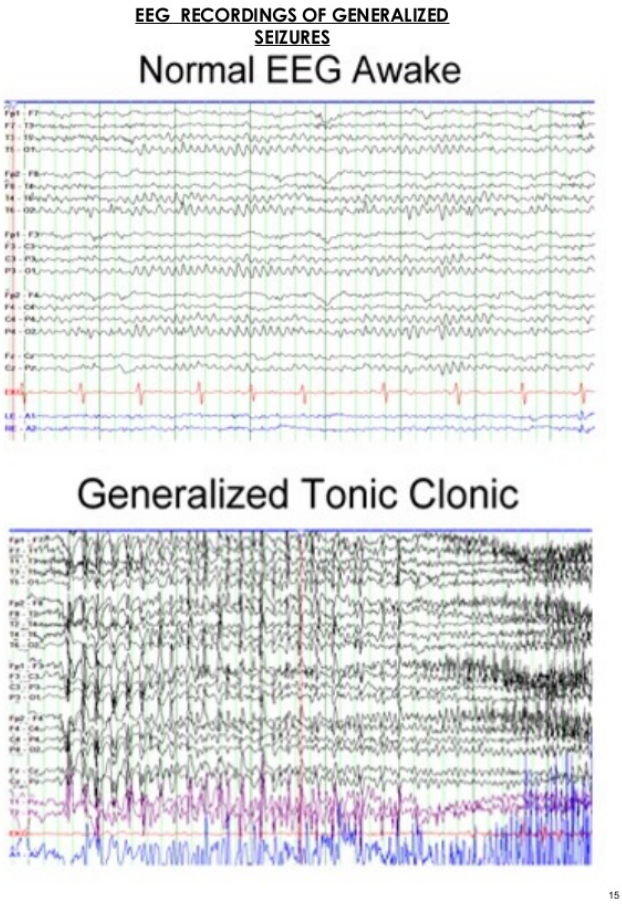

Figure 4. Example of a Normal EEG Recording and an EEG Recording during a Seizure. Source: Mendez (2015).

Examples of the technologies used for measuring the extent of brain damage in a patient are the magnetic resonance imaging (MRI), computerized axial tomography scan (CT or CAT scan), diffusion tensor imaging (DTI), and single-photon emission computerized tomography scan (SPECT). The MRI (as shown in Figure 5) is a big machine that resembles a tube that can fit an average human body inside and "uses a strong magnetic field and radio waves to create detailed images of the organs and tissues within the body" (Lam, 2016). The MRI is a non-invasive tool that can examine inside the human body; display detailed, cross-section images for the diagnostician; and can typically be used to determine spinal cord and brain injuries, abnormalities such as cysts or tumors, joint and back problems, diseases within the organs, fibroids and

endometriosis, and even some infertility problems (Lam, 2016). An example of the cross-section images of an MRI scan is shown in Figure 6.

Figure 5. MRI Machine. Source: Lam (2016).

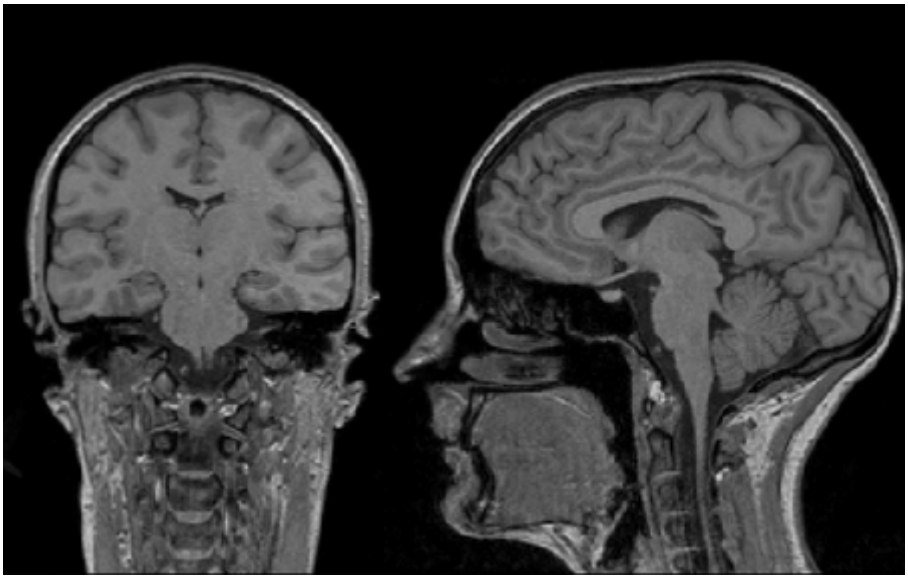

Figure 6. Example of MRI Brain Scan. Source: University College London (2016).

According to Nordqvist,

> The CAT scan uses a computer that takes data from several X-ray images of structures inside a human's or animal's body and converts them into pictures on a monitor. Tomography is the process of generating a 2-dimensional image of a slice or sections through a 3-dimensional object. Similar to looking at one slice of bread within the whole loaf. (2016, p. 1)

This reflects how a CAT scan, much like an MRI, takes cross-sectional views of the body—with one significant difference between the two—the MRI is more detailed in its images. CT scans are often used in the emergency rooms to ensure brain injuries have not advanced to a detrimental state (Brain Injury, 2016).

Figure 7 lists some differences between the MRI and CAT scan.

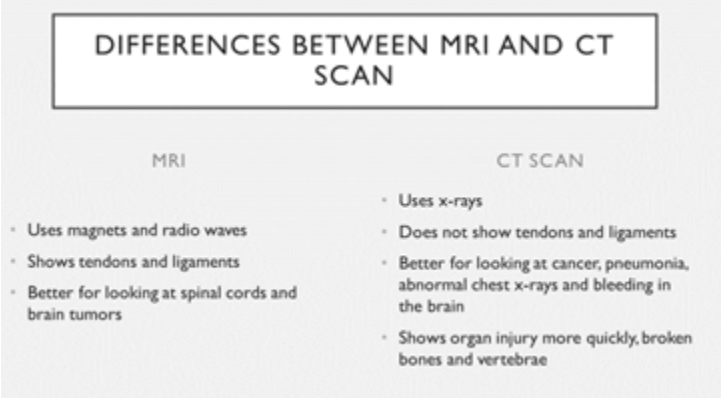

Figure 7. MRI and CT Scan Differences.
Adapted from Ct-Scan-Info.com (2007).

Figure 8 shows a CT machine, and Figure 9 depicts an example of an image from a CT scan.

Figure 8. CT Machine. Source: Cancer Research UK (2016).

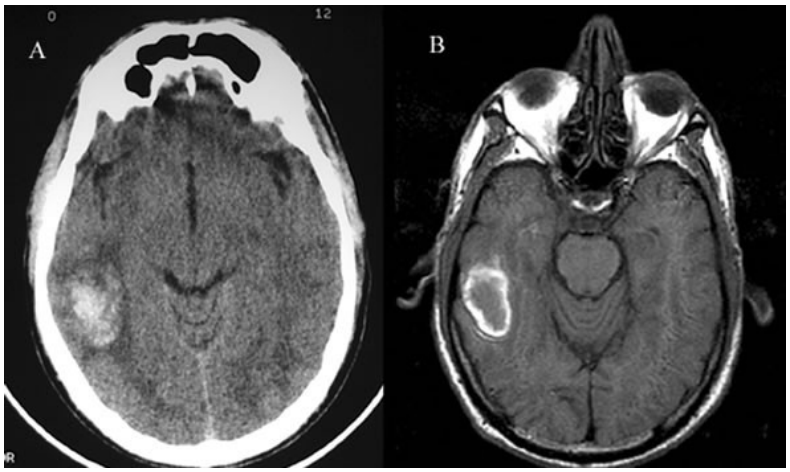

Figure 9. Example of CT Scan. Source: Bermuda Healthcare Services (2014).

The DTI is a type of MRI that uses special software to view parts of the brain a normal MRI cannot detect (Brain Injury, 2016). It is a new technology that "allows for visualization of natural damage to the white matter" (Brain Injury, 2016). These images, like the one in Figure 9, are also useful in diagnosing epilepsy, multiple sclerosis, brain abscesses, brain tumors, mild traumatic brain injury, and hypertensive encephalopathy (Chhabra & Smirniotopuolos, 2015). Figure 10 compares and contrasts the different uses of various diagnostic imaging. Figure 11 is an example of a DTI scan.

PROS AND CONS OF DIAGNOSTIC IMAGING

	STRENGTHS	WEAKNESSES
MRI	Detects soft tissue abnormalities; blood vessels and circulation; no radiation, safe for babies & pregnant women	Enclosed space, which may be problematic for people who are claustrophobic; loud noise levels; expensive machinery
EEG	Accurate timing; can detect deep brain waves; non-invasive procedure	Poor spatial resolution; expensive
CAT/CT	Less restrictions than MRI; accurate; painless	Radiation exposure; some reactions to contrast; not suitable for pregnant women; & expensive

Figure 10. Pros and Cons of Diagnostic Imaging

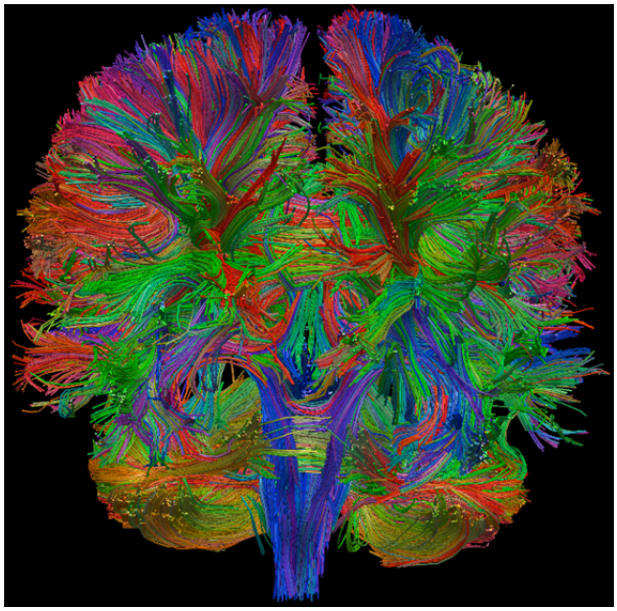

Figure 11. DTI Scan. Siddique (2013).

SPECT imaging is a functional nuclear imaging technique performed to evaluate regional cerebral fluid forced through tissue by the way of blood vessels, called perfusion

(Tam & Gunabushanam, 2015). An example of a SPECT machine is shown in Figure 12. A patient is injected with radioisotopes that emit gamma rays, which allow the machine to view how blood flows through arteries and veins in the brain (Mayfield Brain and Spine, 2016). Early SPECT imaging is important: “because damaged brain tissue normally shuts down its own blood supply, focal vascular defects on a SPECT scan are circumstantial evidence of brain damage” (Brain Injury, 2016). SPECT imaging can assist in the diagnosis of cerebrovascular disease, suspected dementia, seizure focus, brain death, suspected brain trauma, neuropsychiatric disorders, substance abuse, and infection/inflammation (Tam & Gunabushanam, 2015). An example of a SPECT scan is shown in Figure 13.

Figure 12. SPECT Machine. Source: Siemens Healthineers (2016).

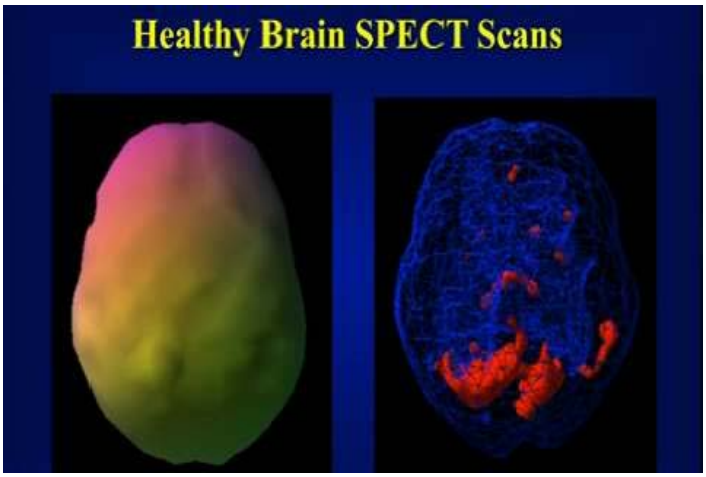

Figure 13. Example of SPECT Scan.
Source: Give Me Wellness (2013).

B. HOW AN EEG WORKS

When someone presents with a suspected head injury, that person needs to be evaluated quickly by a medical professional to ascertain whether further diagnosis is needed from a specialist. If it is determined that specialty care is needed and the patient is not already at a hospital, then the patient is transported to a hospital where he or she is admitted for further care. Often, if the patient does not indicate the presence of seizures, an EEG may not be requested, which could lead to a problematic, undiagnosed condition (Zehtabchi et al., 2013).

In the case of seizures, other than convulsive seizures, there are non-convulsive seizures (NCS) that are seldom diagnosed by ED physicians because the behavior or altered mentation is so subtle that it needs to be defined by an EEG and not by other clinical criteria (Bastani, Kayyali, Schmidt, Qadir, & Manthena, 2005).

Another mental status that can manifest from a head injury is altered mental status (AMS) that is a "non-specific" manifestation of brain dysfunction and is a common presentation in the ED (Zehtabchi et al., 2013). According to Omurtag et al. (2012), "studies show that ED patients with AMS whose initial evaluation includes EEG are diagnosed more accurately and sooner than those without and EEG. (p. 1)"

Usually, patients with a closed head injury will be admitted to the ED to receive immediate care. Due to space constraints and electrical interferences, EDs do not usually house EEGs, so the staff typically requests an EEG reading from a dedicated EEG lab or has the patient transported to the EEG lab to be tested (Bastani et al., 2005). Bastani et al. (2005) described the lack of constant EEG technicians' availablity:

> When the ED physician is able to suspect that the AMS status may be caused by NCS and then orders the EEG, either an EEG technician and EEG cart are called from the EEG lab to perform the test in the ED, or the patient is transported to the EEG lab for testing. This may typically add 30–60 minutes or even up to several hours to obtain the results. Also, many EEG labs are not open 24 x 7 (24 hrs./day, 7 days a week), making EEG unavailable for hours or days sometimes. (p. 2502)

According to (Zehtabchi et al., 2013),

> Despite its potential value in the diagnosis and treatment of ED patients with AMS, EEG remains a difficult test to obtain in the ED. Incorporating EEG into the evaluation of ED patients with AMS requires 24/7 availability of EEG technologists and neurologists. (p. 1582)

Omurtag et al. (2012) explains the reason EEGs are not commonly performed in an ED setting is that

> the long wires leading from the electrodes to the traditional EEG machine act as antennas and often pick up relatively high-voltage ambient electrical noise because of the large number of noise sources in the ED environment. The electrode wires may also constrain movement and limit access of medical personnel to the patient in the typically cramped emergency department setting. (p. 2)

"Recording an EEG in an ED is also often complicated by space limitations, time limitations and the electrically hostile environment resulting from cardiac monitors, infusion pumps, ventilators and so on" (Zehtabchi et al., 2013, p. 1582).

Some EEG machines can be mounted to a cart and transported to the patient for testing, generally after a patient is admitted to an inpatient room in the hospital.

> Grant et al. (2014) describes some space and time constraints that hospitals often encounter,

> Hospital EEG laboratories are rarely open around the clock. Very few emergency departments are equipped with EEG machines or staffed with a technologist who can properly apply EEG electrodes and record a technically adequate study in an environment that is often electrically hostile. The long electrode wires and EEG machine may impede patient movement and limit access of medical personnel to the patient. (p. 1582)

Some factors that inhibit an EEG in an emergency department are that the size of the EEG equipment tends to be inconvenient for an ED setting, where space is often limited; the EEG machine and equipment can be expensive for an ED budget, costing between $20,000 to $40,000 per unit; EDs typically lack the time and expertise required to set up and monitor EEG testing; and there are no dedicated personnel trained to read an EEG if a neurologist is not available (Bastani et al., 2005). Approximately 2% of EDs are equipped with EEG machines or technologists that can apply the electrodes properly and render an adequate study (Omurtag et al., 2012).

If the patient were admitted after business hours or on the weekend, he or she would likely need to be admitted until the EEG technician and neurologist are available. Generally, EEG technicians work during normal business hours (M–F, 9 am–5 pm) and these technicians are specially trained to operate the machinery and connect patients to the electrodes. In some cases, if the patient was admitted on the weekend or Friday evening, depending on the severity of the trauma, they may have to wait for an on-call EEG technician to properly administer the EEG test.

Depending on the type of head injury, if the wait is prolonged over days, the injuries would either resolve on their own or worsen by the time the patient is tested and diagnosed by a neurologist, which makes expedient care imperative. Studies have shown that early neurological intervention has a 55.5% change in the diagnosis and a 70% change in case management (Roberts, Costelloe, Hutchinson, & Tubridy, 2007).

The EEG technician is trained to apply the leads or electrodes using a special gel that attaches the electrodes to the scalp of the patient, which generally takes up to 20–30 minutes in the application process and can be longer when dealing with an uncooperative or agitated patient (Omurtag et al., 2012). After the electrodes are attached, the technician attaches the other end of the electrodes to a computer that records the patient's

brainwaves. The recording process can take up to an hour, in which the patient would need to stay as still as possible so that there is no “noise” or artifact interference (Daly, 2012).

EEGs measure brain activity and are very sensitive to internal and external interferences. Waveforms that are not derived from brain activity are considered to be artifacts, and while some can contaminate the reading, there are others that exhibit physiologic functions that can provide clinical correlation (Tatum, Dworetzky, & Schomer, 2011). Daly described how noise can affect EEG analysis:

> This can include, but is not limited to, subject generated noise such as the electrical responses to eye blinks and head movement, and external electrical noise such as the power line noise at either 50 or 60Hz cable movement, sweating, electrode movement, etc. It is therefore very important to ensure that the EEG is clean and free of these noise artifacts before it is used. This ensures that any analysis results may be attributed to brain functions. (2012)

Once the information is recorded, a neurologist or neurological specialist will examine the results and conclude a diagnosis. According to Tatum et al. (2011),

> artifacts that arise either from the EEG equipment or from the environment are common extrinsic non-physiologic sources. They may be obtained during routine recording but are more common in hostile environments outside the EEG laboratory, where more electrical currents are present (p. 253).

Alternating current is the most common source of artifacts and exists in nearby electrical power supplies of devices or outlets. Again, according to Tatum et al. (2011), “the EEG amplifiers can create inherent high-frequency noise because of molecular ‘movement’ that occurs within the electronic components of machine (p. 253–254).”

Some minimum requirements should be established with the standard EEG to better ensure accuracy of recordings with little interference of noise to skew the results. A dedicated quiet space, away from high traffic and noise to house the EEG, staff, and patients is optimal in order to have a more accurate reading. A minimum of 16 channels must simultaneously record brainwaves, because too few channels lead to more

interpretive errors and more channels decrease the chance of such errors. Additionally, the equipment in the EEG lab needs to be grounded by a common point (Epstein, 2006).

According to Epstein (2006), "recording electrodes should be free of inherent noise and drift. They should not significantly attenuate signals between 0.5 and 70 Hz (p. 86)." The best types of electrodes to use are silver chloride or gold disk that are held on by collodion, and these should be kept clean to decrease noise. According to the International Federation of Clinical Neurophysiology (IFCN), all 21 electrodes and placements should be used to get a comprehensive reading and the 10–20 system is the only one officially recommended by IFCN (Epstein, 2006).

On a patient's EEG record, the minimum identifiers used should be the patient's name, age, recording date, ID number, and the name or initials of the technologist. Attached with the record should be a Basic Data Sheet that includes

> time of recording, the time and date of last seizure (if applicable), the behavioral state of the patient, a list of medications that the patient has been taking, including predication given to induce sleep during EEG, and any relevant additional medical history. (Epstein, 2006, p. 88)

EEG calibration is key and should be done before and after every recording. "It gives a scaling factor for the interpreter and tests the EEG machine for sensitivity, high and low frequency response, noise level, and pen alignment and damping" (Epstein, 2006, p. 88).

A viable alternative to the constraints of the standard EEG is integrating an ambulatory EEG, which will enable portability, ease of use, and accessibility (see Figure 14). When a patient with a brain injury needs an EEG, the medical staff at a clinic or hospital or in the field can easily apply and operate the ambulatory EEG anywhere there is access to the Internet and/or Bluetooth. The ambulatory EEG is comprised of electrodes that are presupposed on a cap that comes in disposable and semi-disposable variations, depending on the preferences of the organization. The electrodes come in "disposable electrodes (gel-less, and pre-gelled types); reusable disc electrodes (gold, silver, stainless steel); headbands and electrode caps; saline-based electrodes and needle electrodes" (Hasan, Rusho, Ghosh, Hossain, & Ahmad, 2014, p. 2). In addition to the

electrode cap, there is an EEG recording device that is roughly the size of a cellular phone, which records and transmits data from the electrodes to a nearby computer. As technology progresses, more ambulatory EEGs are entering the market and have the potential to be more accurate than the standard EEGs.

Figure 14. Example of Ambulatory EEG. Source: Biosignal (2016).

There are a few ambulatory EEGs in the market that are FDA approved and are comparable in accuracy to the standard EEG. According to Dilmaghani et al. (2010), the goal of the ambulatory EEG would be to transmit data wirelessly, through Bluetooth, to a computer or other device, which removes the need for wires that would be traditionally connected to the EEG and reduce signal distortion or artifacts. As previously mentioned, the caps come in disposable and semi-disposable variations with electrodes pre-gelled for easy administration, which makes it more sanitary than using the standard EEG caps. The electrodes attached to these caps are wireless, which diminishes interference from outside noise or artifacts, enabling the ambulatory EEG to be used in more extensive environments than its traditional counterpart.

Unlike the standard EEG, the ambulatory EEG does not require a specialized technician to attach the electrodes, which can be stressful and time-consuming to the patient and staff. Once the cap and electrodes are securely placed on the patient's head,

the device will store the information from the electrodes, can transmit the results to any personal computer within the vicinity, typically within 10 meters, and has the ability to store the information to an on-board memory card (Omurtag et al., 2012). According to Omurtag et al. (2012),

> Custom software running on the PC controls the device, measures electrode impedances (including ground and reference electrodes), displays the signals and impedances, slows the entry of annotations, and writes data to a remote server where an authorized user can review and interpret the EEG. (p. 3)

According to Omurtag et al. (2012), "the ambulatory EEG and standard EEG appear nearly identical, although there is greater high frequency noise in the standard EEG." Although the ambulatory and standard EEGs appear identical, there is a subtle difference. According to Grant et al. (2014), "the diagnostic accuracy and concordance of ambulatory EEG are comparable to those of standard EEG, but the unique ED-friendly characteristics of the device could help overcome the existing barriers for more frequent use of EEG in the ED." According to Grant et al. (2014), "the diagnostic accuracy of microEEG is not compromised by the use of an electrode cap suggests that EEGs adequate for the ED setting can be recorded by personnel other than trained EEG technologists." These examples reflect the similarities and differences between the different EEGs.

Some advantages of long-term EEGs are that they are

> capable of recording, analyzing and storing large quantities of information; able to make post hoc changes in the recording; able to upgrade new software applications; able to perform quantitative EEG (QEEG) or brain mapping, with spectrographic analyses; able to perform multimodal monitoring; and education of personnel may be easy with computer experience. (Tatum et al., 2011, p. 254)

Ambulatory EEG caps and devices can range from $200–$10,000 depending on the number of channels the device records on and the manufacturer.

Some disadvantages of long-term EEG use are that

> it requires a dedicated technical support team; needs regular maintenance of the equipment and calibration; false detections of software applications

> may be cumbersome; initial investment cost for equipment and personnel high (depending on the manufacturer); evolution of technology may make current techniques and software obsolete; and personnel may be unfamiliar with the recording system (which is the reason for thorough manufacturer training on device and system). (Tatum et al., 2011, p. 254)

Some further limitations to the ambulatory EEG are that, for the device to be able to send information to medical professionals who are not readily available on-site, the device needs to have an Internet connection. While Internet connectivity may not be considered an obstacle for most facilities, this could potentially raise a concern for those who may be located in remote areas. The device is also powered by batteries and could possibly consume a lot of power if used aggressively for long periods of time, such as during sleep studies where patients may need to wear the device overnight. As newer models enter the market, dual powered battery and electrical brands may help alleviate this problem.

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II. USE CASE

A use case analysis describes detailed steps on how to implement a system and the scenarios in which the system will be best utilized. Use cases address the "actors" or people that will use the technology; the goal or purpose of the technology and how that impacts the actors; pre-conditions and post-conditions, or what must happen before and after the use case is administered; the main flow, in which the primary scenario is proposed for the system; the exceptions describing possible failures that can occur with the system and alternative flows that are possible with the use of the system; and the stakeholders that can be affected by using the system (Cockburn, 2011).

A. ACTORS

In a hospital or medical center, the actors are the physicians, including ED physicians and neurologists, nursing staff, medics, supply clerks, healthcare administrators, the information technology department, the contracting department, and the patients. ED physicians initially assess the patient by using the MACE assessment tool to determine whether he or she may need further specialized care from a neurologist. Neurologists examine the EEG readings and provide a diagnosis that will determine the next level of care for the patient. Therefore, it is important for a neurologist to be integrated to the ER staff. By being fully staffed to the emergency department or on an on-call status, they are accessible to the ED and can give immediate and more accurate diagnoses to patients that have experienced head trauma.

Nursing staff or medics would attach the EEG cap to the patient and operate the EEG device. These people must be trained, initially by the manufacturer, on the proper use and care of the ambulatory EEG caps and device. Subsequently, the trained staff can then cross-train other staff members on how to properly apply and use the device on patients.

The supply clerks are the staff who take scheduled inventory of stored medical supplies/equipment and order additional supplies when the stock is low. They must work

in conjunction with the medical staff so that they are aware of the correct re-order point for the accessories that are needed to operate the device.

Healthcare administrators will be involved with the medical staff in determining the quantity of devices the facility would need and the type of model that would function best for the staff and patients; ascertaining the storage needs for the device; and determining the budgeting needs when the devices have been integrated in the department. For the hospital administrator to assist the medical staff in determining the correct quantity of devices, they will need to analyze past data to discover the average number of patients that have presented with TBIs and the average number that have required EEG readings. This will give them some baseline information on determining their initial purchase and can subsequently order more devices and accessories, as needed. Healthcare administrators may be involved in the process of acquiring and distributing the ambulatory EEG device and its equipment to the various departments. They will also be involved with contacting the manufacturer for product training and maintenance.

The information technology (IT) department will be involved in ensuring that the digital EEG recordings are secured and encrypted when being transmitted or downloaded to a provider through the DOD's electronic medical records called AHLTA, which works in conjunction with the military's Composite Health Care System (CHCS).

The contracting department is involved in managing and acquiring supplies and equipment from civilian vendors through the bidding process. Here, vendors compete for the government contract to be the sole supplier for the system. Once a vendor or manufacturer is chosen, by placing the lowest bid, they would need to provide guidance and training on operating and maintaining the system, as well as any repairs that may be needed under their warranty.

Patients will use the ambulatory EEG device and will be advised on the preliminary preparations involved before the device can be administered. They will also be informed of the appropriate behavior required to obtain the most accurate EEG reading.

B. IDENTIFYING THE GOAL

The goal of this use case analysis is to develop the most appropriate plan to implement the ambulatory EEG device for the use in the field, clinics, and hospitals within naval medicine. Using this device will reduce unnecessary admissions and time spent in the hospital, expedite the time between a patient's injury and the time they are evaluated by a neurologist, and decrease subsequent costs involved.

C. DEFINE THE PRE-CONDITIONS

There must be a need for the ambulatory EEG device. While in the field, there is a higher probability of a marine or sailor experiencing a TBI. Due to the topographical and geographical nature of some deployments, the presence of a standard EEG machine is not practical nor feasible. When someone has presented with a TBI, depending on the severity, they would need to be medically evacuated to a facility that is equipped to attend to their needs. Typically, these facilities are far from where the person was injured, which can exacerbate the injury depending on the extent of damage that occurred.

D. IN A CLINICAL SETTING

Typically, standard EEG machines are not housed in a clinical setting unless the clinic has a neurological specialty within it. This is due to staffing, space, and cost constraints. If a patient reports to their physician that they have incurred a head injury, he or she will usually be referred to the ED for further testing and analysis.

E. IN A HOSPITAL SETTING

The hospital is the most common place that treats patients that have experienced TBIs, seizure disorders, and so on. Unfortunately for many, the time constraints on the usage of the EEG machines in the labs when specialty staff are not there is limited. The patient will need to be admitted and monitored until the EEG technician can either transport the bulky machine to the patient's room or transport the patient to the EEG lab for testing.

F. DEFINE THE POST-CONDITIONS

The successful result of this use case is to incorporate the ambulatory EEG device into naval medicine, to provide the best affordable medical care by delivering immediate assistance to injured service members, dependents, and veterans in the theater, clinic, or hospital setting.

G. MAIN OR BASIC FLOW FOR AN EMERGENCY ROOM SITUATION

In an ED setting, when a patient presents with a head injury or trauma, the main, basic flow is as follows:

1. The patient enters the emergency department via ambulance or ambulatory.
2. The patient is triaged by the nursing staff.
3. The patient is sent to the emergency room to be seen by an ER physician.
4. The ER physician makes a preliminary assessment of the extent of the trauma, using the MACE (Defense and Veterans Brain Injury Center, 2016a).
5. The ER physician requests various tests (blood tests, MRI, CT scan, EEG, and others) to understand the full extent of the injury and probable damage.
6. The EEG is ordered by the physician.
7. Medic and/or nursing staff retrieve ambulatory EEG device and accessories within the ED.
8. Nursing staff places the wireless cap on patient's head, turns on the device, and commences the EEG, without having to move the patient to another location.
9. At the completion of the test, the data is transmitted digitally to a personal computer or tablet located within 10 meters of the ambulatory EEG device.
10. The information is also stored on a memory card in the device.
11. The data is encrypted through custom software supplied by the manufacturer and is sent to the on-call neurologist and is placed in the patient's medical record.

12. The neurologist assesses the data, diagnoses the patient's head trauma, and gives any recommendations from the diagnosis to the attending physician.

13. If necessary, the attending physician and neurologist may collaborate on whether the patient will need to be admitted for further treatment or be discharged from the ED to another department in the hospital, or whether the patient is fit to go home

14. The use case ends (see Figure 15).

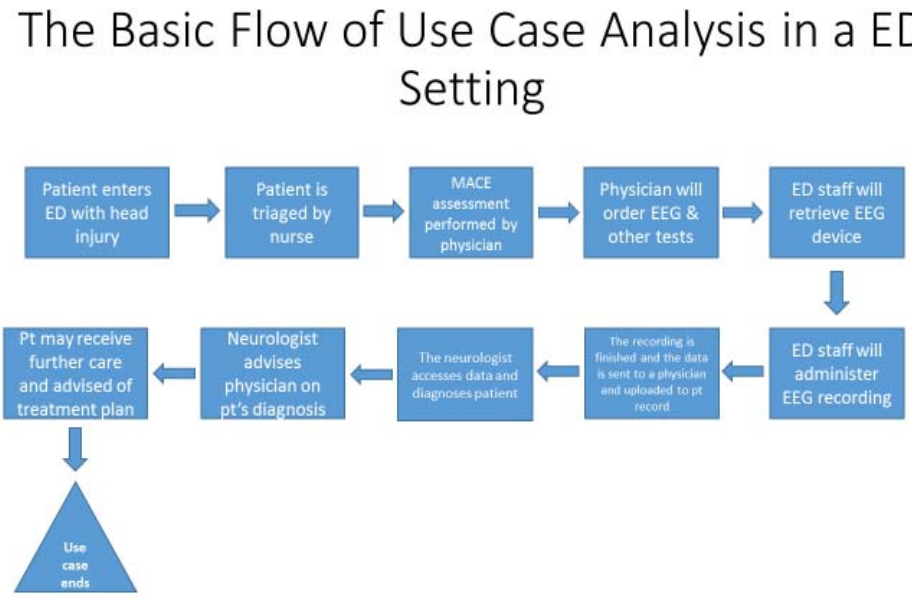

Figure 15. Basic Flow for ED Setting

H. MAIN OR BASIC FLOW IN A CLINICAL SETTING

In a clinical setting, when a patient has a non-emergent seizure disorder or sleep disorder, the main, or basic, flow is as follows:

1. The patient checks in at the front desk.

2. The patient will fill out paperwork describing the reason for the visit to the clinic.

3. The patient will wait to be escorted to the exam room where his or her weight and vitals will be recorded.

4. After vitals are taken, the patient will wait for the physician or healthcare provider to authorize the EEG test. The medical assistant or nurse will apply the electrode cap to the patient and begin the EEG recording.

5. When the recording is finished, the data is added to the patient's medical record where the physician can access it.

6. After a physician has assessed the data and diagnosed the patient, the physician will give the patient further directions on the next step for his or her treatment plan

7. The use case ends.

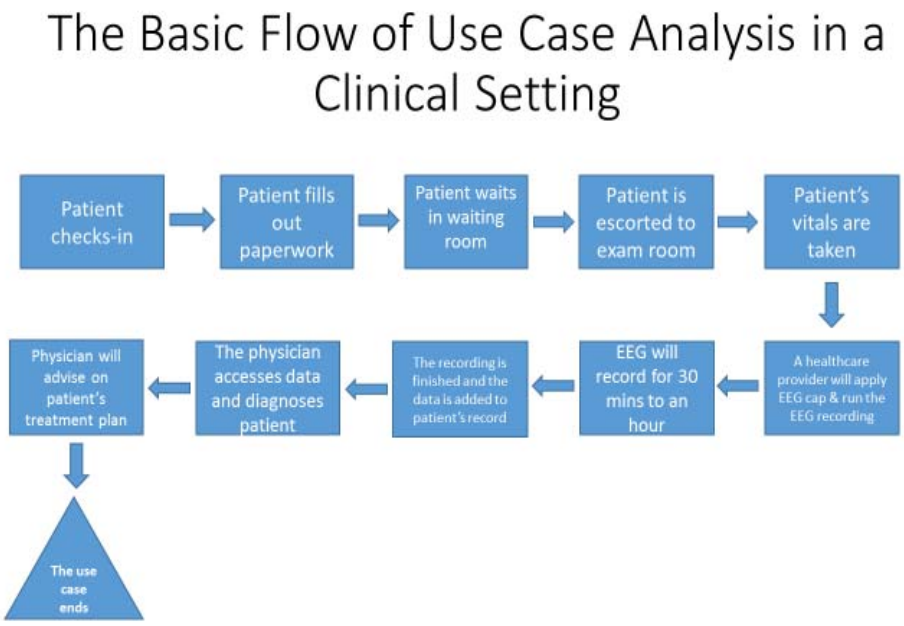

Figure 16. Basic Flow for Clinical Setting

I. MAIN OR BASIC FLOW FOR A FIELD/COMBAT SETTING

In a field/combat setting after a patient has suffered head trauma and is moved to a stable location where medical professionals are located, the main, or basic, flow is as follows:

1. A physician uses the MACE assessment to ascertain the extent of the head injury.

2. A medic will ensure patient is stable and administer EEG recording.

3. Once the test is finished, the medic will need to make sure that there is an Internet connection so that the information can be sent to a neurologist for analysis.

4. The attending neurologist will receive the data and assess whether the patient is fit to continue with the mission or may need to be medically evacuated to a medical treatment facility to receive further, emergent care.

5. The use case ends.

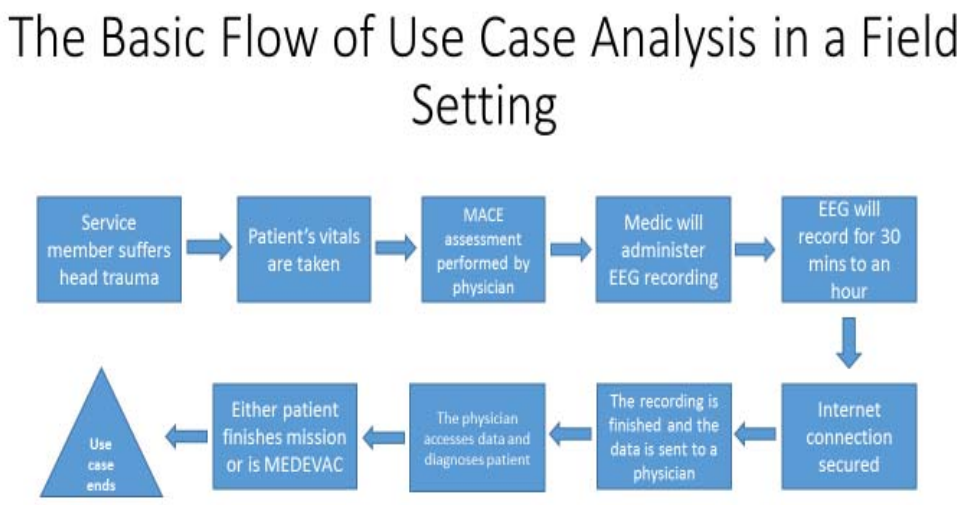

Figure 17. Basic Flow for Field Setting

J. LIMITATIONS

Some exceptions that could interfere with the accuracy of the readings would be if the patient was combative or agitated. This has the potential to cause the readings to be inaccurate because the movements of the patient could produce electrical inaccuracies (artifacts) that would translate into the EEG recordings. Therefore, the patient must be calm and as motionless as possible, in order to obtain an accurate EEG reading.

The ambulatory EEG operator must ensure that the device has enough power to complete a full reading, thus ensuring that the batteries are replenished or recharged (depending on the brand acquired) appropriately so that it is always in a state of readiness. Even though some brands can run up to 25 hours straight at maximum load,

care must be taken to ensure power-readiness of the device (Pinho, Correia, Sousa, Cerqueira, & Dias, 2014).

As the researcher had little to no access to medical professionals, the information and data provided were referenced from medical journals and websites. There was some difficulty finding costs for ambulatory EEGs due to many manufacturers keeping that information undisclosed. However, the researcher did find a wide array of costs from overseas manufacturers on a public website and therefore documented the lowest and highest costs for the EEG caps and devices.

The last exception or limitation would be the lack of Internet connectivity to send the recordings via email to a neurologist. If there is no Internet connection where the EEG recording will be administered, the information can be stored on the SD card within the EEG device until an Internet connection is available and the information is sent to a neurologist for further examination. For example, if a service member in theater sustains a head trauma and has an EEG performed on him or her, but the site lacks connectivity, it forces the corpsman to make a medevac decision without consulting a neurologist or physician.

III. RECOMMENDATIONS

The ambulatory EEG can potentially be used on a ship or in a submarine environment. If someone has suffered a head injury within the confined spaces of a ship or submarine, it would be beneficial to have the ambulatory EEG to ascertain whether the injured would be fit for duty after some rest or whether he or she would need to be medically evacuated for further treatment.

In addition to supporting the military armed service members, the ambulatory EEG could be used for their dependents, specifically, in the neonatal intensive care unit (NICU) and pediatric intensive care unit (PICU), with infants and children that have experienced brain injuries and need to be evaluated by neurologists. The EEG caps would need to be altered to fit the size of infants and children, which could range from premature babies to 12-year-old children.

These EEGs would also be very beneficial to military and bomb-sniffing dogs who may experience increased incidences of brain injuries due to the nature of their jobs. Veterinarians would be able to consult with veterinarian neurologists on an appropriate treatment, without having to transport the animal unnecessarily, which could distress the animal further and exacerbate the injury.

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IV. CONCLUSION

Studies suggest that the ambulatory EEG is comparable to the standard EEG in its accuracy and has less sensitivity to artifacts, which makes it more stable and versatile for use outside of an enclosed environment, such as an EEG lab. As military medicine advances, and more service members are experiencing mTBIs, the ambulatory EEG can be used in environments that are not as stable for use with the traditional EEG and can be used effectively for early diagnosis in the treatment of head injuries. This reflects the versatility of the ambulatory EEG not only for service members but again for their dependents as well (e.g., NICU/PICU). This use case analysis has highlighted the importance of research and treatment of servicemen and women affected by traumatic brain injuries and the varying diagnostic tools used in determining the best course of action concerning the care given.

As a diagnostic tool, the EEG determines the extent of a brain injury but has been underutilized due to its size, artifact sensitivity, and user specialization. The ambulatory EEG establishes its portability, comparable accuracy, and user friendliness when compared to the standard EEG machine. The use case analysis outlines how the ambulatory EEG can benefit naval medicine in the ED, clinic, and field setting while saving space, costs, and man hours. As technology progresses, the ambulatory EEG could be useful for diagnosing infants and children who have suffered brain trauma, be used on ships and submarines, and assist with diagnosing military and bomb sniffing dogs in veterinary medicine.

The ambulatory EEG makes it possible for any doctor’s office, clinic, ED, or personnel in a remote area to send the information to a neurologist and get a diagnosis and treatment plan that can provide expedient assistance to a patient affected anywhere in the world. The ambulatory EEG device can prove to be useful to naval medicine, especially when service members are deployed to remote areas where extensive medical attention is not readily available. This can save on unnecessary testing and transportation costs that could ensue if the device were not present and utilized. The ambulatory EEG has shown results comparable to that of the standard EEG and should be used at least as a screening tool, due to its portability and accessibility for those with suspected brain injuries.

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